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Quantifying the Value of Preconditioning in a Montney Inversion Workflow

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Summary

Seismic data preconditioning is a vital step in optimizing the inputs to pre-stack AVO inversion workflows and generating results more consistent with other measured data. Preconditioning can include denoising, amplitude and alignment corrections, and spectral operations on migrated gathers as well as on angle stacks. As AVO inversion for elastic properties depends on variations of seismic amplitude with offset, these steps are critical to achieve improved accuracy. In this case study, we demonstrate the effects and value of properly preconditioning seismic data prior to inversion, using a Montney dataset. A focus is placed on noise removal and proper event alignment, in both gather and angle stack domains. AVO inversion is conducted on seismic both with and without rigorous preconditioning applied. The inverted elastic properties from each workflow are compared and related to porosity. Porosity or pseudo-porosity logs from wells are compared to the inverted porosity. In this way, we can directly assess inversion performance, and thus the uplift of the seismic preconditioning workflow.

Theory

This section provides a brief, high-level overview of the applied preconditioning operations, AVO inversion, and the reservoir characterization methods. Normal-moveout (NMO) velocity errors in seismic data have consequences for calculating the AVO gradient and thus the subsequent inversion. A Swan RMO (2001) workflow is followed, whereby an analysis of the complex AVO gradient and intercept is undertaken, to remove NMO stretch errors. The imaginary part of the correlation coefficient between the intercept and gradient is proportional to the NMO velocity errors. By picking a NMO velocity that reduces the correlation to zero, a new velocity field can be generated, and NMO corrected gathers are produced.

Radon demultiple on seismic gathers is a simple method to remove multiples, conducted in the tau-p domain. The migrated gathers are transformed to the tau-p domain by the parabolic Radon transform (Hampson, 1986). Applying a mute in the tau-p domain based on event moveout time, removes dipping events which correspond to multiples in the time domain. Transforming back to the time domain we produce data free of multiples, or at least dipping events.

In AVO inversion, an elastic model of the subsurface is calculated, that produces angle-dependent reflection amplitudes observed in seismic data. An Aki-Richards (1980) linearized Zoeppritz approximation based inversion is used to compute the angle-dependent reflectivities. Here, partial angle stacks are inverted simultaneously for changes in acoustic impedance, shear impedance, and density.

Alignment of seismic events in the angle stack domain is important for properly capturing the true AVO response of each seismic event, and the associated lithology. While the Swan RMO corrects for much of the residual normal moveout in the data, some RNMO still remains after angle stacking. The QeyeWarp is a seismic alignment algorithm that applies a smoothly varying displacement field to align angle stacks to a reference stack. The warping seeks to locally optimize the correlation coefficient of the energy envelope of adjacent angle stacks, iterating from near to far stacks. A displacement field is calculated for each angle stack to align it to the adjacent stack, and these are summed to align any stack to the reference angle stack. This algorithm is amplitude preserving, and is indifferent to the input amplitudes, so polarity reversals from AVO signatures are accommodated and preserved.

Method and Workflow

The first step of the workflow was to apply a conservative Residual Moveout correction (RMO) on the migrated gathers. This is conservative in that a limited near offset range is included in the AVO statistics calculation, to reduce effects from large NMO stretch errors. Thus, the RMO correction is smaller and based on the more certain nearer offset data. This first pass of RMO allows for more accurate discrimination between dipping multiples and moveout. Next, we apply a strong radon demultiple, filtering events with 100ms moveout at 5000m offset. This demultiple is observed to have significant effects at improving resolvability of events in the target interval (Figure 1). Normally, a milder radon mute would be applied, particularly since a radon demultiple is inherently non-AVO compliant. However, the goal of this study was to push the data as much as possible to achieve maximum uplift. By plotting the residuals, or the difference between the radon input and output, a radon mute of 100ms was determined to strike a balance between noise removal and signal preservation. The demultiple is followed by a harsh RMO correction, this time including farther offset data in the AVO analysis, resulting in a greater correction, particularly at higher offsets.

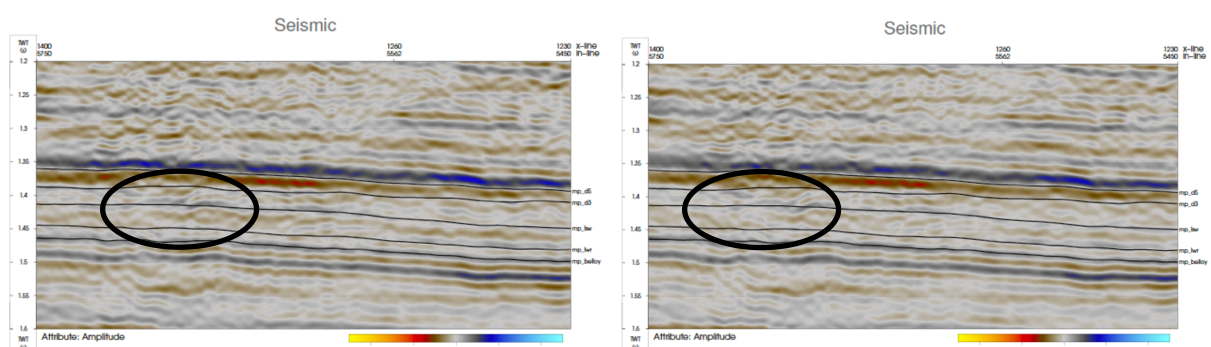

Figure 1: 20-25 ° angle stack before and after preconditioning. Note areas of increased resolution, reduced NMO stretch

After the iterative gather preconditioning is complete, the data is stacked into partial angle stacks, such that each angle range has similar fold coverage, out to 50° incidence angle. The angle stacks are then warped to the 10-15° reference stack. This correction is quite small in magnitude, as much of the residual moveout errors have already been corrected in the gather domain. This warp is applied to make final alignment corrections between each angle stack. The final preconditioned angle stacks are shown in Figure 2.

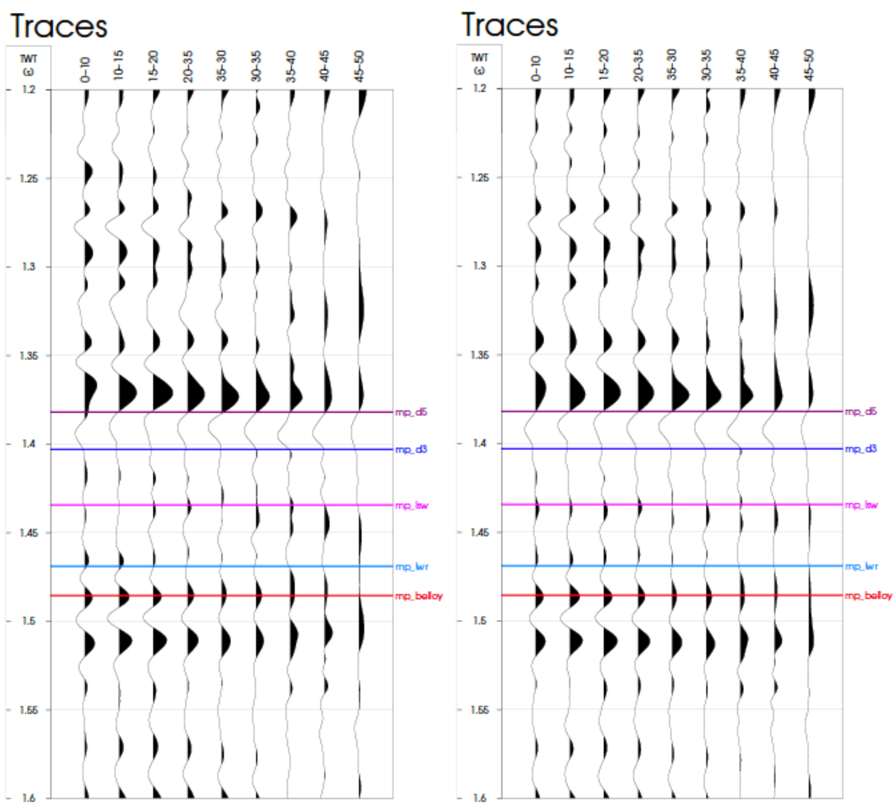

Figure 2: Angle stacks at a well location before (left) and after preconditioning (right). Multiples above (~1.25s) and within (~1.44s) the target interval are visibly removed.

A pre-stack inversion is then run, to estimate P-Impedance (Zp), and S-Impedance (Zs). Both the preconditioned data, and seismic without the full preconditioning workflow applied were inverted, to directly compare the uplift of the preconditioning. These elastic results can be related to petrophysical properties through a rock-physics transform, where quartz volume intervals are identified in the elastic space and correlated to porosity values. These estimated values are validated at well locations against petrophysical logs, or relationships to drilling parameters. Drilling and well log properties can be related to elastic or petrophysical properties through transforms and relationships (Su, 2016). Rate of Penetration (ROP) of the drill bit correlates to the compressive strength of the formation, and therefore Young's Modulus. Taken further, Young's Modulus relates to Shear impedance

It was found that small changes in inverted properties relate to seemingly small (~2%) changes in porosity in the target interval. However, this small porosity difference has economic consequences to drilling locations and targets.

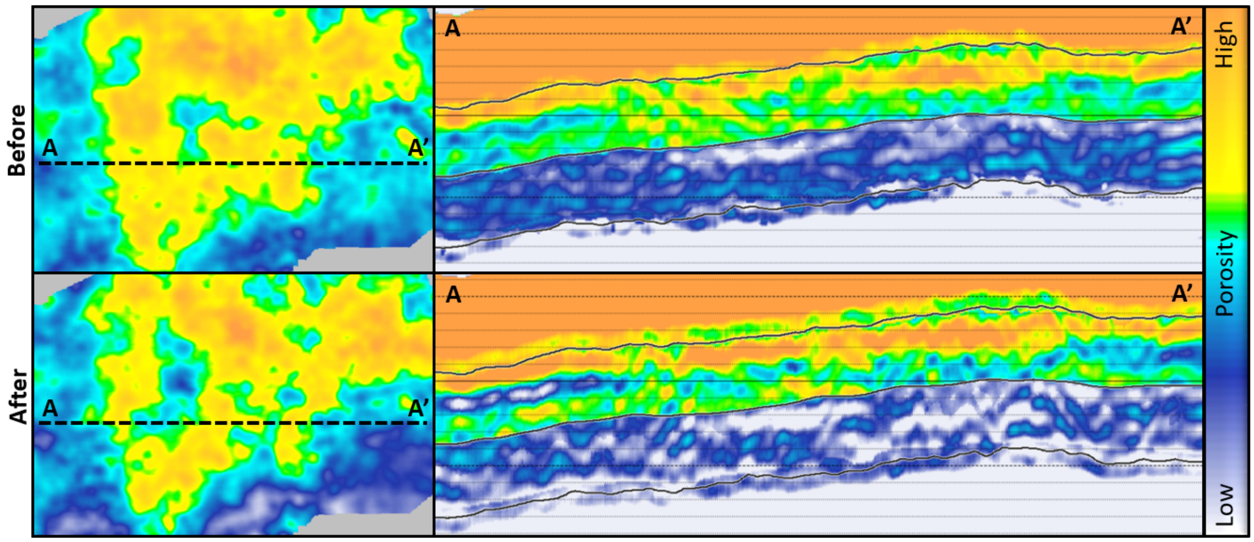

Figure 3: Inverted seismic porosity estimate displaying average of a Montney interval and seismic cross-section before (above) and after preconditioning (below). Small changes in porosity are observed with increased continuity in central portion of seismic.

Results, Observations, Conclusions

Validation of inverted elastic or petrophysical parameters at well locations is the most important measure of the effect of preconditioning on the inverted seismic data. These inverted parameters are used to guide future production and exploration decisions, and thus there is a high economic importance in making the most accurate prediction possible. In this study, we have demonstrated that by applying careful and considered conditioning to seismic data prior to inversion, the accuracy of petrophysical estimations generated from the inverted parameters can be improved, allowing better informed drilling decisions.

By inverting and validating seismic both with and without this preconditioning applied, we have directly quantified the uplift of running a careful, full preconditioning workflow prior to pre-stack inversion.

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References

Aki, K., and Richards, P.G., 1980, Quantitative Seismology. W.H. Freeman & Co.
Hampson, D., Canadian Journal of Exploration Geophysics, VOL 22 (1986); P. 44-55
Su, O., Sakiz, U., and Akçın, N.A., 2016, ISRM International Symposium EUROCK, Cappadocia, Turkey
Swan, GEOPHYSICS, VOL. 66, NO. 6 (NOVEMBER-DECEMBER 2001); P. 1735–1743